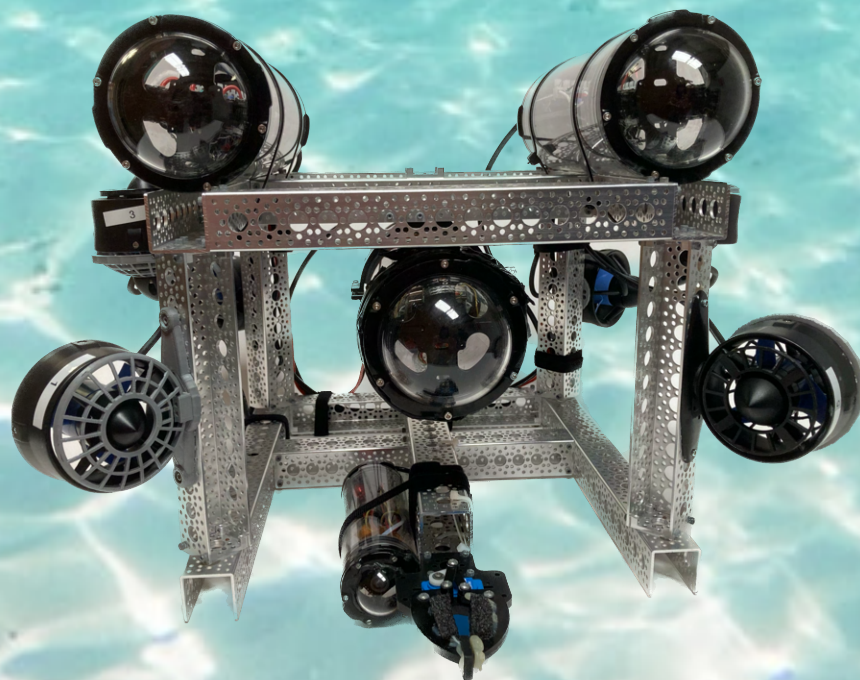
TECHNICAL DOCUMENTATION

MATE WORLD CHAMPIONSHIP

HEPHAESTUS ROBOTICS

TALOS III



HEPHAESTUS ROBOTICS
X-ACADEMY
SANTA CRUZ, CA USA

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ABSTRACT

Hephaestus robotics is an organization founded in Santa Cruz, California, USA. The team is entirely independent and composed of a diverse range of students from across five different high schools and three counties. Our mission is to produce innovative remotely-operated underwater vehicles that address pressing environmental concerns. Our newest ROV design, Talos III, is a unique solution to our most important challenges: maintaining sustainable energy systems, protecting endangered species and monitoring planetary health. The oceans hold the key to addressing these problems, and Talos III is well equipped to work within the marine environment to help address these needs. Talos III has a unique architecture that is flexible and able to adapt to a wide range of mission-specific tasks, from performing visual inspections of energy installations and fish habitat, to deploying and installing equipment.

The Hephaestus team works with a collective philosophy that fosters both specialization and collaboration with each team member taking ownership of a specific aspect of the project, and bringing their knowledge to the broader team.

This technical document illustrates the accumulation of the past seven months of work from our entire team.

TEAMWORK

PROJECT MANAGEMENT

COMPANY PROFILE

Hephaestus Robotics is an independent team composed of innovative students from numerous schools in the Santa Cruz, CA region. Our team creates unique ROVs ideal for stewarding native sea life and supporting sustainable energy systems (Fig. 1).

The following year, we expanded our operations by renting a 1,600 square foot Maker Space and growing to 21 members, which required a much more robust organization of roles. Each member was responsible for part of designing the ROV as well as part of the business aspect of the team.

This year, we have 12 members and we are focusing on a reliable and robust design.

Hephaestus Robotics is not associated with a school like other teams but rather with the X Academy, a 501(c)(3) nonprofit that provides STEAM enrichment programs to kids in Santa Cruz County. Hephaestus team members come from eight different schools.

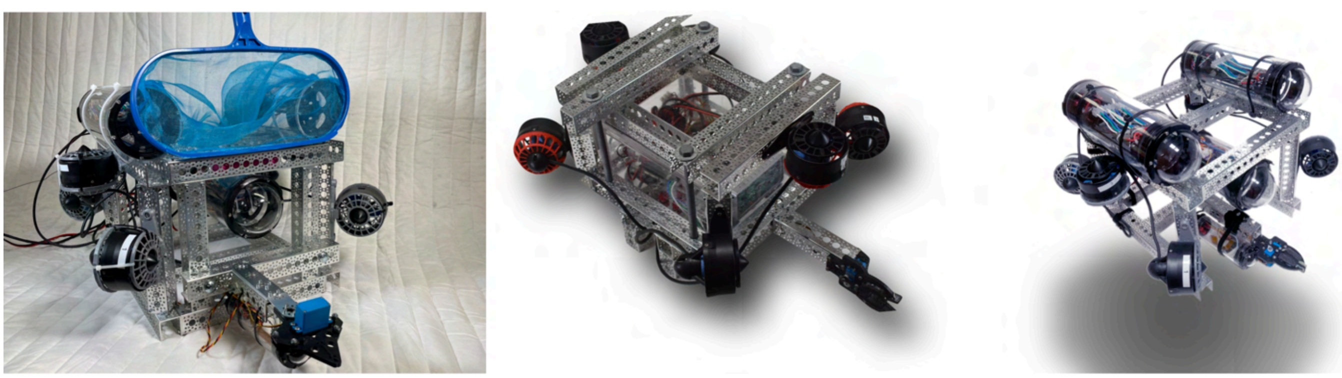

Fig. 1. Talos I, II, and III. Credit: Nathan Madsen, Tim Madsen, and Scot Herbst.

TEAM ORGANIZATION & ROLES

The leadership team is composed of the co-CEOs, and Senior team members who participated in previous years. The leadership team is Andrew Sylvester, Om Shastri, Ojas Shastri, Ben Hillard.

The entire team meets weekly on Sundays from 1 PM to 4 PM and occasionally on Saturdays. During this time, people are working on various tasks solo or in small teams, and no member worked on just one part of the ROV. We wanted every person to experience and work on what they were interested in. Members occasionally worked on weekdays to ensure that goals were met on time. The team and mentors use Discord, a group communication platform so that members can keep each other updated on their work. Email is used for more important information such as registering for the competition. In order to share files such as CAD drawings or documentation writing, across team members, a shared Google Drive was created. Github was used to share code between members. These platforms allowed for quick and reliable sharing of files and information.

PLANNING AND SCHEDULING

In October of 2022, leaders and mentors from last year's team met to plan for this season.

The entire team meets weekly on Sundays from 1 to 4 pm. Leaders meet the day before to plan goals for the week. At this time, most people are working on engineering tasks or meeting with business teams. Members occasionally worked on weekdays to ensure that goals were met on time. Below is the schedule and future plan as of writing this document.

SCHEDULE

Start Date	End Date	Task
October 2022	October 2022	Select Leadership Team and Develop Plan
October 2022	January 2023	Rebuild frame and build new ROV tools
November 2022	January 2023	Recruit Team Members
January 2023	January 2023	Review Competition Manual
December 2022	January 2023	Purchase new components
February 2022	March 2023	Assemble Test Props
February 2023	March 2023	Rebuild electronics and enclosures
January 2023	March 2022	Update Software to Use New Electronics
January 2023	March 2023	Design and Build Float
March 2023	March 2023	Write Technical Report
March 26, 2023		Initial Test of ROV in Water
March 2023	April 2023	Continue Testing and Refining ROV
April 2023	April 2023	Practice for Competition in Pool
April 22, 2023		Monterey Regional Competition

Fig. 2. X Academy Robotics schedule.

DESIGN RATIONALE

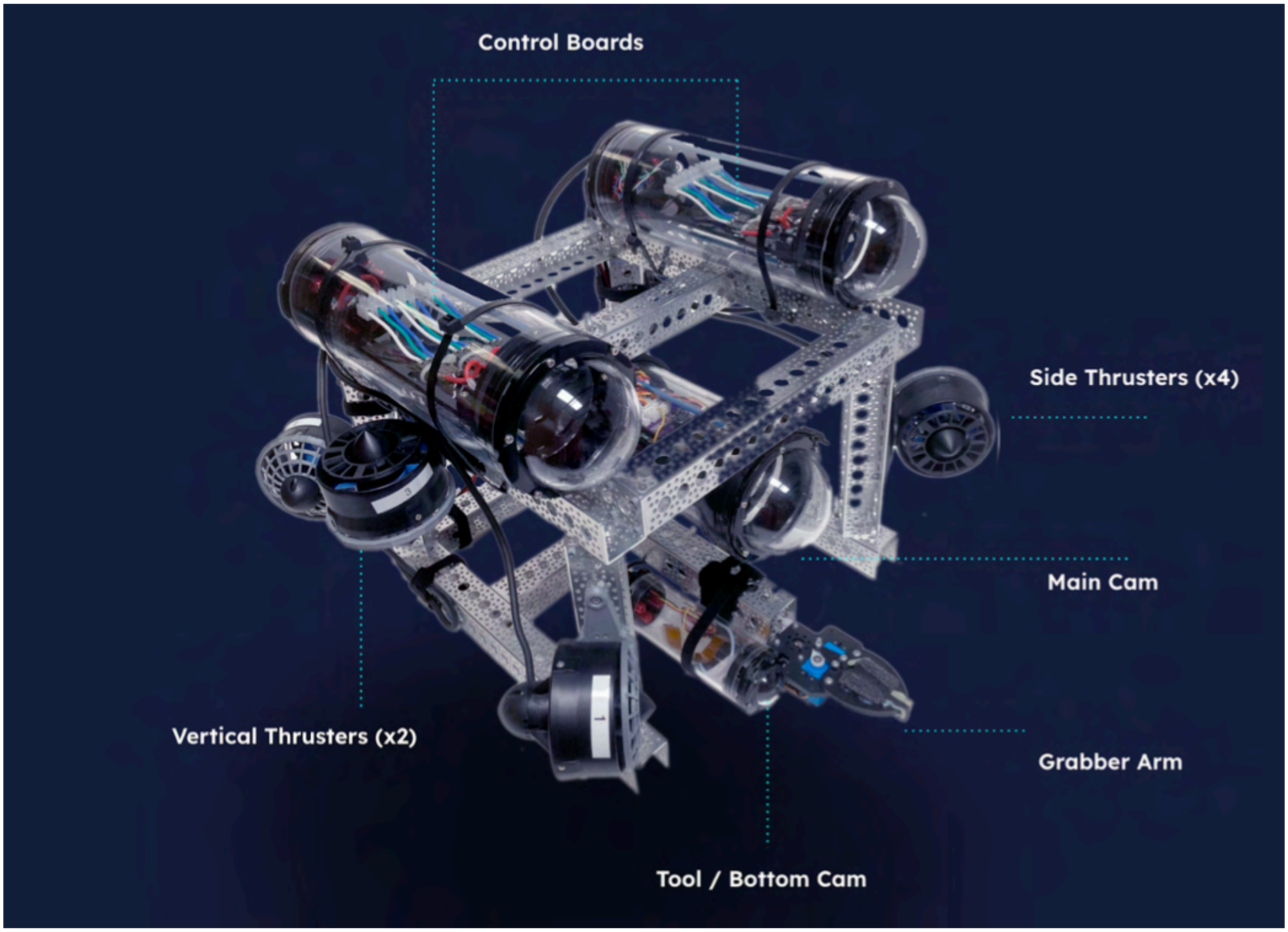

Fig. 3 Talos III overview

ELECTRONICS ENCLOSURES

The ROV electronics are split across three 4″ tubes from Blue Robotics. This is a change from last year's design which housed electronics in an acrylic box that we designed, laser cut, and assembled in-house. We chose to use the 4″ tubes because last year at the competition, the box leaked and the electronics were fried. We fixed the electronics in time for our second product demonstration however we did not want to risk a fatal leak again this year.

Electronics are mounted with standoffs onto custom designed laser cut trays that fit into the cylindrical enclosures.

FRAME

Four translational motors are attached to vertical channels rotated 45 degrees, making a vectored motor design (Fig. 3). Two vertical motors are attached to the channel on the front and back. The horizontal gripper tool sticks out from the front on a piece of channel.

We continued using the aluminum channel due to its strength and its modularity which allowed for rapid prototyping. The Actobotics system uses side tap pattern mounts to attach aluminum channel segments. Pieces can be attached to each other in many different places, similar to Lego blocks. When we were designing a mechanism to compress the O-ring and seal the electronics box, the ease of assembly allowed us to test many designs in the span of one meeting. Additionally, the reusability of the aluminum channel—as compared to 3D printed or laser cut materials—allows us to remain environmentally conscious while making innovations. We bought the channel in bulk, saving 50%, and cut it to the desired length using a chop saw.

CONTROL/ELECTRICAL SYSTEM

ONBOARD ELECTRONICS

Talos III's onboard electronics are split into one main tube and two identical side tubes. The main tube houses a Raspberry Pi model 4B with our custom made Raspberry Pi hat. The Pi hat receives 12V power from the tether. It distributes 12V power to the ethernet switch and it steps that down to 5V to power the Raspberry Pi. A PCA9685 chip on the hat allows the Raspberry Pi to send Pulse Width Modulation (PWM) signals to the motor controllers. These signals are carried over a Cat 6 cable to the side tubes via a PWM to Cat 6 chip from ServoCity. The Raspberry Pi also has a Raspberry Pi camera connected to it via MIPI CSI-2 cable.

The side tubes each contain 3 Blue Robotics Electronic Speed Controllers (ESCs) and a chip converting PWM signal from Cat 6 to servo cables. The PWM signal enters through a penetrated Cat 6 cable and the motor controllers connect to the servo cable output from the chip. Three T200 thrusters are wired to their respective ESCs with a terminal block. The ESCs are connected to the incoming 12V power with another terminal block.

CUSTOM ELECTRICAL COMPONENTS

Talos III includes two custom made electrical components; a custom Raspberry Pi Servo HAT and PWM power switch. Both components were designed using KiCad, a free open source PCB development software.

The custom-made Raspberry Pi HAT (Fig. 4) is an innovative solution specialized to the ROV to simplify internal wiring and free up space inside the main tube and is based on the SparkFun Pi Servo HAT it replaces. The custom board was adapted from the open-source design of the SparkFun Pi Servo HAT to use JST connectors and a power delivery system with a 12V input and 5-12V outputs was added. The power outputs on the board simplify the internal wiring of the ROV by directly powering the ethernet switch and Raspberry Pi using custom-made wires, eliminating the need for an additional power lead and bulky USB Buddy. Combined with the more secure JST connectors, the custom Pi HAT reduces the chance of failure by reducing the amount of components in the main electronics tube and by lowering the risk of connectors coming loose, which improves the serviceability and repairability of the ROV.

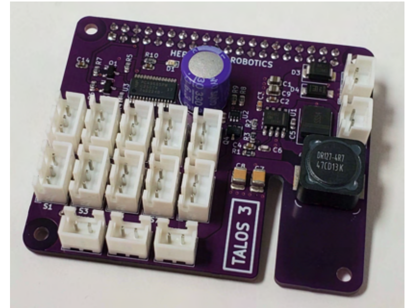

Fig. 4. Talos 3's custom PCB. Credit Bennet Menzer

The PWM power switch (Fig. 5) is a simple solution to providing a 12V power output to the task-specific tools of the ROV. The switch takes advantage of the PWM outputs of the Raspberry Pi by using the signal to control a mosfet that turns on and off the 12V power output.

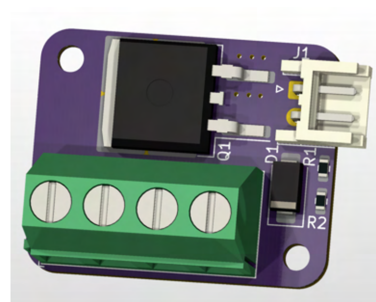

Fig. 5. Custom PWM power switch. CAD render by Bennet

The main risks with designing a custom parts are design or functional errors and replaceability. To avoid these problems, the team went through multiple board iterations and consulted a qualified electrical engineer to ensure there were no design errors, and assembled multiple additional copies of the custom boards to use as backup replacement parts.

TOPSIDE CONTROLS

The topside setup has a laptop for the pilot and a laptop for the scientist, who handles tasks that require analysis of camera feeds. Both computers connect to a router and the tether Ethernet cable connects to the router. This puts all computers on the same network with the Raspberry Pi so that they can access the camera feeds.

The pilot's computer is connected to an Arduino Uno over a USB port. The Spektrum controller for piloting communicates to its receiver over Digital Spectrum Modulation (DSM) protocol. This sends a radio signal at 2.4GHz to the receiver. The Arduino then reads the data about the controller's inputs from the receiver in PWM signals and sends it over serial to the pilot computer. The pilot computer takes this information and calculates the desired velocity for each motor and sends the corresponding PWM value to the Raspberry

Pi. The Raspberry Pi runs each channel on the servo hat at its given value. The ESCs receive this signal and deliver the necessary power to the motors.

The Spektrum controller has two joysticks with two degrees of freedom. These four channels are mapped to heave (forward/backward), sway (left/right), yaw (turning), and heave (up/down). There is a binary switch on the controller that opens and closes the vertical gripper.

SOFTWARE

The Raspberry Pi 4 runs a Python program that streams the video feed from its camera to the network over HTTPS internet protocol. We used the Flask Python module to configure the HTTPS server and feed the HTML file with video to the server. Any computer on the network is able to access the video by typing in the Pi's IP address and the port that it is streaming on into the web browser search bar.

The Pi also has a Python program that handles the controls. It receives datagrams in the form of arrays with 16 numbers, each corresponding to the PWM signal that should be sent from one of the 16 channels on the Pi hat. The topside pilot computer sends these Serial packets. It receives the data from the Spektrum controller, calculates the signal for each motor and then forwards this data to the Pi over User Datagram Protocol (UDP). This protocol was chosen because it is simple to set up and although it is known for a tendency to loose packets, packets are being rapidly sent so it doesn't matter if a single packet is lost.

All of our code was written in Python because it is simple to learn and code with and it has a large library of packages and documentation. Many of the electronics we used came with Python code already available to test the parts.

NETWORK DIGITAL INTERFACE (NDI)

The Network Device Interface (NDI) protocol allows the Raspberry Pi to receive camera footage from a pi camera and relay it to the https server, which is then accessed by OpenCV and displayed in the grafana dashboard using an embed link. Before being sent to the dashboard, OpenCV takes each frame of the feed, finding the brightest points in the image, and circles them. These bright points resemble the lasers, and thus this software is designed to be applied to lasers. There is a function in the Python program that uses known distances between the cameras to find the distance between where the lasers are hitting and the rover.

TETHER

Talos III has a compact tether made up of two 12 gauge wires for power and one gel-filled Cat 6 cable for data. Cat 6 cable contains four braided pairs, eight total conductors. Two pairs connect the onboard ethernet switch to the router at the surface. The other two pairs connect the laser power to a shutoff switch at the surface.

Last year, we found that water leaked through the outer jacket of normal Cat 6 cables. Gel-filled cables mitigate this problem because the gel can keep water out if there are scratches on the cable

Talos III's tether has to be managed in a specific way as to not damage the ROV, entangle the ROV, and/or cause a tripping hazard during operation. Because of this, we have designed a protocol to manage the tether. Tether management is a two person job, with a main tether manager and assistant tether manager. Before launching the ROV, the tether is laid out in a coil where it can be easily unwound. Any knots or tangles must be dealt with before launch. When everything is ready, the ROV is lowered into the water and the tether managers begin to actively manage the tether. The main tether manager maintains an appropriate amount of slack. They give and take away slack throughout the operation as needed. The assistant tether manager is responsible for ensuring that the tether is coiled neatly, as well as looking out for the main tether manager. While the tether managers provide the backbone of tether management, the pilot also has some responsibility. To help mitigate entanglements, the pilot will try to not spin any more than necessary in any one direction.

Penetrators are located on the rear lid of each of the three tubes, which are responsible for carrying power, motor, servo, and Cat 6 Ethernet cables between tubes and to the surface. Venting penetrators (labeled OK) were also installed on all tubes. This allows for quick installation of the lid by letting excess air escape.

PROPULSION

Talos III uses six Blue Robotics T200 thrusters for propulsion. Two vertical thrusters control heave and four horizontal thrusters in a vectored configuration provide surge, sway, and yaw (turning). We cannot run the T200s at their maximum speed otherwise we would use more power than allowed for the Ranger class.

31.21A * 20V * 6 thrusters = 3745.2W > 300W.

We instead run the motors at 12V and the motor software limits the speed of the motors so they cannot draw more than 2.5A. To determine this speed, we used data from the manufacturer that shows the current draw for varying voltages and PWM signals:

When running the motors at 12V, PWM values between 1320 microseconds and 1680 microseconds draw less than 2.5A (Fig. 6). Manufacturer data also shows that with these values, the motors output 10.59 Newtons when running forwards and 8.53 Newtons when running backwards.

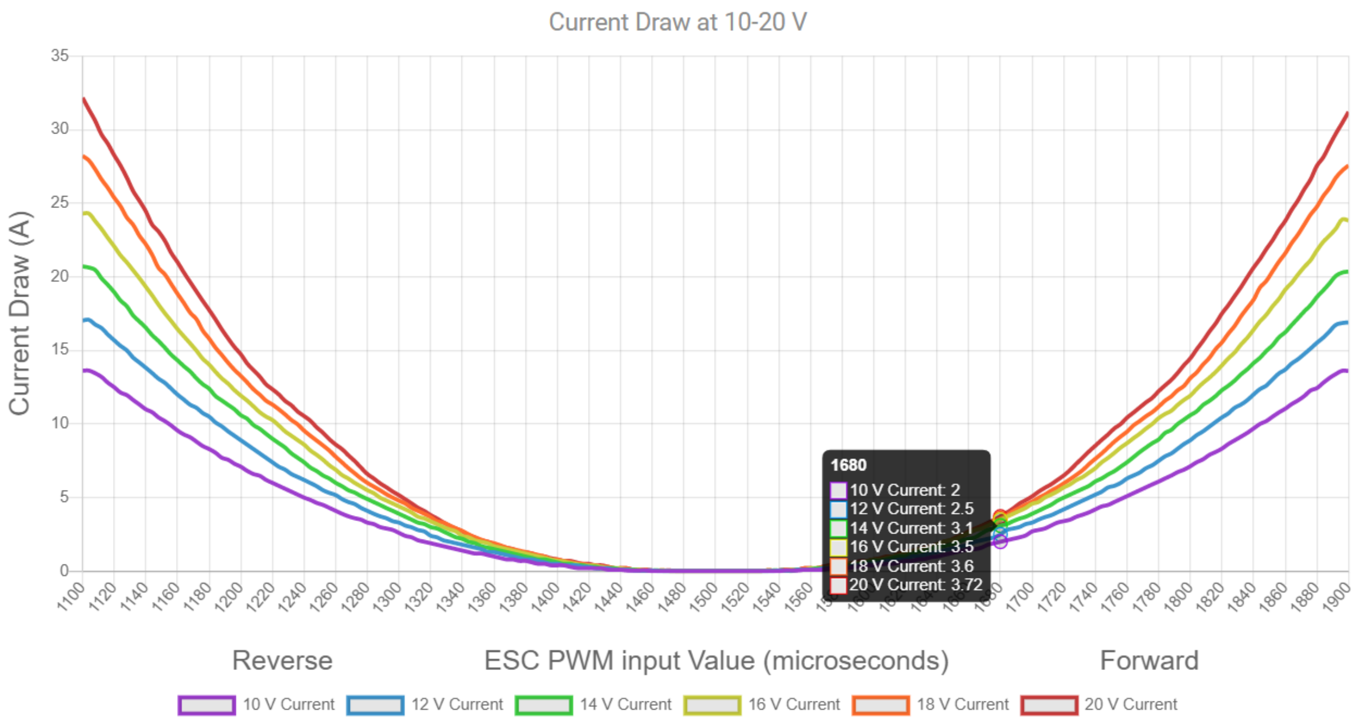

Fig. 6. Motor power draw.

The lateral motors are mounted diagonally to the ROV itself, allowing us to use a vectored control scheme, and thus have 4 degrees of freedom rather than 3. The ability to move the ROV side to side is very useful for positioning the gripper to grab something. We

We had 6 spare T200s from Talos I which we used on Talos II. This saved us $1,200 worth of new motors. The spare motors were never used so their quality was not compromised. Other thruster options were Blue Robotics T100 motors, less power draw but no longer sold, or bilge pump motors, much cheaper but harder to mount, less power efficient and weaker. T200s were the rational choice given that they performed well on previous models and we had spares.

BUOYANCY AND BALLAST

Talos III's buoyancy comes from the electronics enclosures. These enclosures are located such that the center of buoyancy is above the center of mass, ensuring that the ROV is stable in orientation while in the water. By using fishing weights and pool noodles, we are able to quickly and precisely increase and decrease the buoyancy of specific areas of the ROV. This gives us a high level of control over the buoyancy and the orientation in the water. We also designed the ROV to have a slightly positive buoyancy so that in the unlikely scenario where we lose control of thrusters and can no longer pilot to the surface, the vehicle will float to the surface and be easily recovered (Fig. 7).

Item	Quantity	Mass (kg)	Extended Mass (kg)	Volume (m^3)	Density (kg/m^3)	Buoyant Force (N)
Electronics Tube and Electronics	3	4.62	4.62000	0.00904	511.06	43.05
T200 Thrusters	6	0.34	2.04000	0.00019	1,757.11	-8.65
Aluminum frame	1	1.74	1.74200	0.00073	2,386.30	-9.94
Ballast in Electronics Chamber	1	1.40	1.40000	N/A	N/A	-13.72
					Total Buoyant Force:	3.64

Fig. 7. Buoyancy calculation.

PAYLOAD AND TOOLS

TOOLS

Talos III has a horizontal servo-powered gripper, a fish deployment box, a flashlight, and a pump. The whole team watched the Mission Fly-Through video and determined that a horizontal gripper can accomplish most of the tasks with ease. The gripper is reused from last year because that servo setup worked well for us before.

CAMERAS

Talos III features two cameras. The main Raspberry Pi camera faces forwards inside the main electronics tube and it is used for navigation. The second Pi camera is connected to a Raspberry Pi Zero inside a small tube that is mounted on the metal frame near the gripper (Fig. 8). The frame has multiple 3M Dual lock strips in several positions and orientations that allow the camera to be quickly repositioned during a mission to alternate views which allow it to get the best possible view of what the ROV is manipulating. The dual lock solution to repositioning the camera avoids the need to use additional cameras or electronics that would add unnecessary complexity to the ROV.

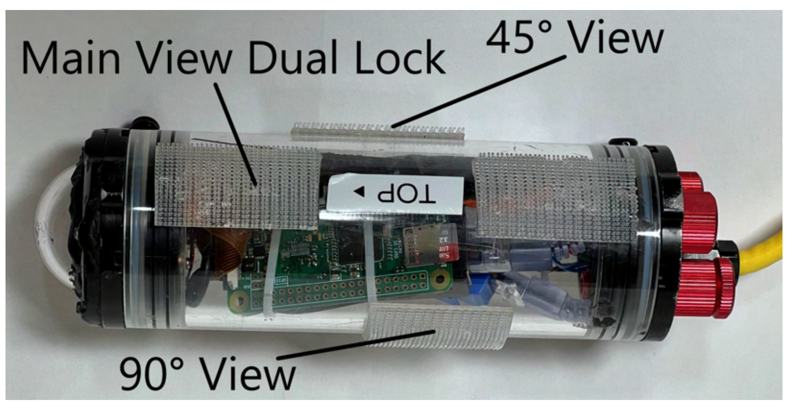

Fig. 8. Variable mounting camera enclosure. Credit Bennet Menzer

LASER DISTANCE MEASUREMENT

In preparation for its ocean health role in stewarding ecosystems, the X Academy team began developing a distance measurement tool before the mission tasks were announced.

There are 2 lasers, each one angled at 1.5 degree inward. This allows the ROV to measure the distance away from an object.

Figure 9 details how to calculate the distance away from an object. "Z" represents the distance from the ROV to the given object, "X" represents the distance between the two lasers (how it appears in the camera), and "Y" represents the distance between where a laser appears in the camera and where it is located on the ROV.

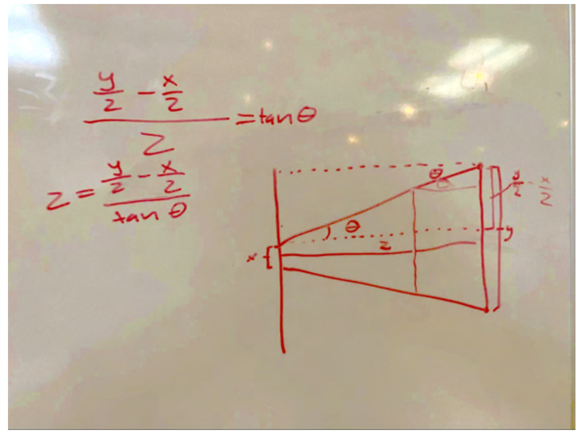

Fig. 9. Calculation of distance measurement. Credit Xander Coomes

3D OBJECT SCAN

To support the mission of stewarding coral we built an ROV capable of automatically generating 3-dimensional models of objects in the environment. None of us had experience with this type of software, so we first researched how to do this. To automatically make a 3D model we decided that photogrammetry, gaining 3D data from a 2D photo, would be the best choice. We then found AgiSoft's MetaShape software which would automatically take in photos and, with a little preprogramming, generate a model automatically.

To collect those photos, we have Talos III drive in a circle around the object while taking roughly 20 photos. At first we planned to have it take as many photos as possible in the time it took to drive around the object (approximately 300 photos), but after trying this method it took way too long for our software to generate a model. Through some testing, we discovered that a model could easily be generated from only 10 or so photos in a little over a minute, albeit with some 'holes' where the software was unable to generate a part of the model. To avoid those 'holes', we settled on 20 photos and, with even more testing, verified that our procedure made an accurate model within 2 minutes.

This model however would not include any dimensions of the scanned object, a requirement for the mission. For this we decided to use lasers. From research we found that lasers are one of the simplest solutions for getting this information. We already had a camera feed, and using the calculations described above made a simple implementation of OpenCV software that would give us the distance from our ROV to whatever surface the laser was incident with.

In order to mount the lasers to the ROV, the team settled on a 3D printed enclosure for the lasers and camera. This is a fully new addition to the ROV design, requiring time for design and manufacture. As a part of the custom laser measurement system, the cost savings is significant.

A team member researched the project using Fusion 360 forums among other sources. The resulting design has holes where the lasers are inserted, a front plate with 4 holes to mount a camera and routing holes for cable management (Fig. 10). Fusion 360 was used to make the design. Then it was 3D printed.

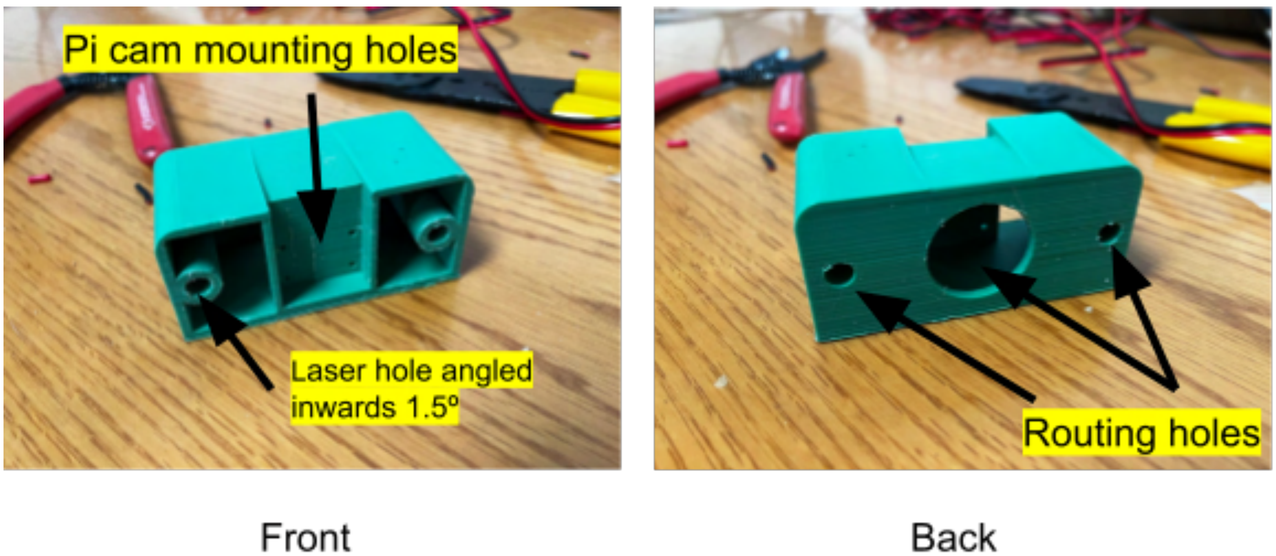

Fig. 10. Laser and PiCam enclosure. Credit: Max Herrera

TASK SPECIFIC TOOLS

Upon viewing the task demonstration video for this year, the team realized that their single fixed gripper could not complete two of the tasks: administering RX to diseased coral and collecting a DNA sample from a coral. By designing a custom tool for each of the two tasks, it eliminates the need to completely redesign the gripper to include a more complex robotic arm and allows for efficient completion of the difficult RX and eDNA tasks. The team developed a modular mounting design that allows for easy tool mounting and dismounting on the front of the robot, which minimizes camera obstruction from the tools by stowing them while they are not in use. The custom switches for turning off and on the tools were mounted inside the tubes of the ROV to lower the amount of waterproofing needed for the onboard electronics on the tools.

For the fish reintroduction and release task, we brainstormed ideas to pioneer our own approach that was more streamlined and accommodated our single gripper arm design for our ROV. For instance, the MATE animation suggests that the fish are released by rotating their container upside down to dump the fish out. There are a few issues with the MATE reference design approach---this design doesn't address keeping the fry contained in their transport box, and it requires a complex multi-axis grabber arm. We designed an enclosed transport box to contain the fry, that utilizes a simple trap door to release them.

Our solution allows for the safe and contained transport of the fry, and allows for a seamless and reliable release through the bottom trap door of the enclosure. It keeps the fish safe and reduces the amount of movement and transition shock for them.

BUILD VS. BUY, NEW VS. USED

Throughout the building of Talos III, we made several decisions on what to build in our Maker Space and what to buy from outside the company. In making these choices, we had to consider the time we had and the specific requirements we wanted from our parts and the overall benefits of building versus buying.

Because our Maker Space includes a large amount of robust tools, including an Ultimaker 3D printer and a Full Spectrum laser cutter, we were able to build much of the ROV and its systems quickly. The speed enabled effective iterative design. Our custom 3D-printed laser mount, used to measure dimensions of underwater objects (e.g. coral heads), went through many iterations before we were fully satisfied. Through a cycle of CAD modeling, 3D printing and testing, we were able to build this highly specific part that met our desires in a fraction of the time that would have been required had we bought a custom part for each design.

Vulcan II, our float, also shows the advantages of building. Inside the float we use custom laser cut plates and a 3D-printed Raspberry Pi computer mount that allow a compact and robust design. In making the float, we redesigned many of the key elements and then were able to apply those redesigns quickly. To add limit switches for more advanced control of the float, we had to remake the acrylic plates, which only took an afternoon versus the several days needed for shipping from a manufacturer. Flanges that secure the syringes in the buoyancy engine went through a similar process when we swapped three syringes for one large one. Through building custom parts, we were able to make highly specified parts quickly.

There were also many situations where buying parts from highly regarded sources was optimal. Raw, high-quality materials for construction, including acrylic plate, PVC piping, printer filament and many other important substances were purchased when we were unable to recycle what we had. We purchased components of the ROV when it would save time or we were not equipped to make a better version than what was available on the market.

The 4" acrylic cylinders that house Talos III's on-board electronic parts were purchased from Blue Robotics, a manufacturer highly regarded by professional underwater robotics companies. For Talos II, our 2022 ROV, we made a custom laser-cut acrylic electronic box. Although much cheaper to make ourselves, it came with unexpected problems, such as being very difficult to effectively seal from water. To avoid this, we used the electronic chambers we had purchased for and used on Talos I (our 2021 ROV) which we knew had a strong, water-tight seal we could rely on. For all the parts purchased for this year's ROV, including electronic speed controllers, lasers, and an acrylic tube for the float, building was determined to be a waste of time and money. That being said, we did not have to make many purchases as we already had a considerable amount of parts.

NEW VS. REUSE

We reused numerous spare parts from Talos I and Talos II; every important component of Talos III apart from the motor controllers and custom PCB were from previous years. This reduced the cost for this year dramatically. We also knew that all the parts were fully functional without having to test them. Additionally, the Raspberry Pi was already fully configured to run on a Talos, simplifying any software work to transfer files and configure the computer.

One significant new part is our custom PCB. The custom circuit board replaced a SparkFun Pi HAT and a USB Buddy to send control signals and distribute power to components and tools, reducing the clutter of the electronics chambers. This new part was highly specific to our needs, and we did not have any used parts that could do what we wanted.

Other new parts include: ESC's we bought to replace damaged ones, a new tether sheath that replaced the zip-ties keeping it together before, and new penetrators that connect wiring to the electronics chambers we replaced to ensure high-quality parts were protecting the valuable electronics.

SYSTEM INTEGRATION DIAGRAM

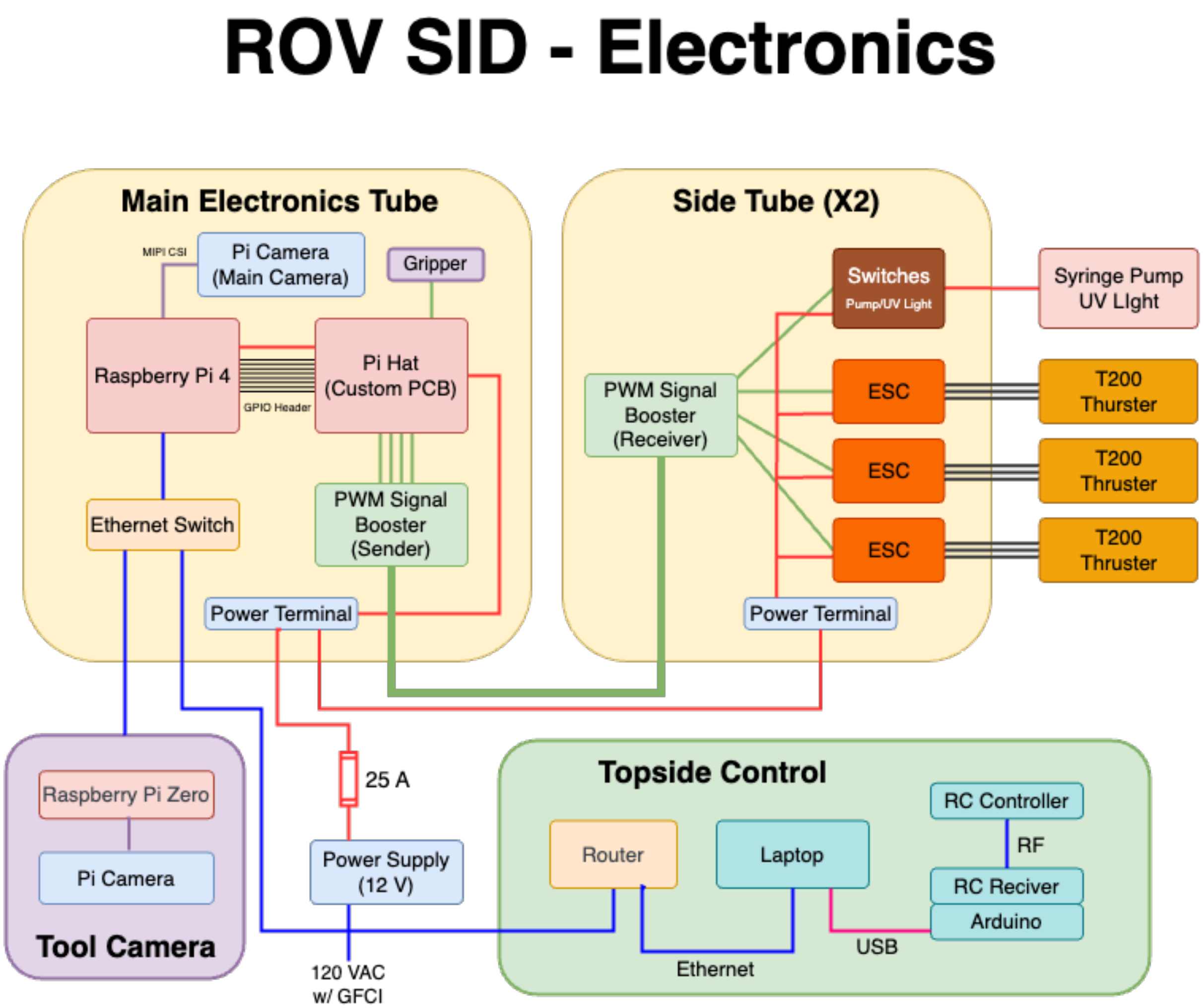

Fig. 11 Systems integration diagram

FUSE CALCULATION

Component	Quantity	Amperage	Voltage	Wattage
Raspberry Pi w/Pi Hat	1	3A	5V	15W
Ethernet Switch	1	40mA	12V	0.5W
ESCs	6	15A total, 2.5A each	12V	180W
Servo	1	1A	5V	5W
Total		**200.5W/12V=16.7A<25A**		200.5W

Fig. 12. Fuse Calculation.

SAFETY

As a company, we have a responsibility to keep everyone safe. Measures have been taken to ensure the safety of everyone working on the construction of the ROV, as well as anyone who operates, handles, or interacts with the ROV.

Ear plugs are provided while activities with a high noise level are being carried out. Latex gloves are required to handle any hazardous chemicals, such as acrylic cement and PVC cement. Team members are given instruction by mentors on operating power tools before they are used. Adult supervision is required when team members cut materials or do activities with a risk of injury. Spark-shielding gloves are required to protect from metal sparks while cutting. Safety goggles are required for anyone operating power tools or doing any activity that could create airborne debris.

When operating the laser cutter, it is mandatory that an adult that knows how to operate it is present. The laser cutter must be watched the whole time when the laser is running, in case the laser lights the material on fire. In the case of a fire, or any other fault, the laser cutter has a large red button to shutdown the whole machine. A CO2 fire extinguisher is placed next to the laser cutter to put out electrical fires without damaging equipment. A fume extractor with a HEPA filter is attached to the laser cutter to absorb fumes from cutting materials like wood and acrylic.

All members are vaccinated against COVID-19.

SAFETY PROCEDURES

Pre-Operation checks	• Closed toed shoes must be worn • Safety glasses must be worn • Operations personnel are all focused and ready
Power On	• Listen for speed controller beeps signaling that the ROV is receiving power • Visually confirm that Raspberry Pis, cameras, and Ethernet Switch are receiving power by checking indicator lights • Test connection to main and secondary raspberry Pi by pinging from computer terminal • Connect to video feed for the main and secondary cameras to confirm their functionality • Connect control transmitter to computer • Run control software and test thrusters by lightly moving them to confirm their functionality • Activate gripper to test functionality
Deployment	• Two capable people present and ready for tether management and lifting *Talos III* • Deck clear and not slippery • Tether is neatly coiled, not strewn across deck • Confirm strain relief • Carefully pick up ROV with two people
Connection Lost	• Verify Connection is lost ◦ Check if any of the camera feeds are working ◦ Check if motion is working • Make sure all ethernet cables are plugged in fully • Power off ROV, wait a few seconds and then power on • If connection isn't back within a minute after power cycling, have tether team pull the ROV to the surface manually to inspect and repair the ROV.
ROV Failure	• Power off ROV • Pull to surface and out of the water and unplug vent plug from leaking chamber • Gently remove electronics from chamber and drain and dry electronics chamber • Check penetrator panel for source of leak • Patch the leaking penetrator with coaxial seal and electrical tape • Check integrity with vacuum pump before redeploying

Fig. 13. Safety procedures.

CRITICAL ANALYSIS

TESTING AND TROUBLESHOOTING

We save time and materials by modeling parts first and then printing/assembling them. Another core concept of our testing methodology was testing our equipment and ROV on land before doing aquatic testing. This way, changes to our ROV can be implemented faster and more efficiently.

In terms of CAD modeling, we wanted to save money by modeling things before spending money on physical parts, and we wanted to catch mistakes digitally prior to 3d printing. One example is from last year, in the design of Talos II. One thing we made via CAD modeling was the base of the electronics box; we originally set it out to be made of ¼ inch acrylic, but later decided to use ½ inch acrylic for strength. We were able to realize this mistake prior to printing. Another problem we encountered was that the base was then too large to fit in the frame in its ½ inch form, so we needed it to be made smaller. This iterative process allowed us to gradually achieve the correct width of acrylic for our box.

Prototyping is an important part of the process we go through when designing and implementing new features for the ROV. An example of our heavy reliance on prototyping is the fish release tool. Before we began modeling our current box design in Solid Works, we made a prototype version out of foam core in order to make sure it would function to our standards. By doing this, we made sure we would spend our time and resources making a tool we knew would eventually work. Once we passed this step, we began designing the box in Solid Works, and laser cutting our first version. We made a lot of mistakes in this first iteration—the box couldn't even be assembled—and learned the importance of making sure everything fits together in CAD before we try to construct it. Additionally, we figured out that we needed to improve the way that the box was attached to the gripper on the ROV, which we also made a prototype of from foam core. Once we improved our CAD model and designed an efficient way to attach and remove the box from the gripper, we arrived at our current version of the fish release mechanism, which we wouldn't have been able to get to without prototyping in every step of the design and implementation process.

For the wiring and electronics, last year we needed to pot our cables with epoxy, which meant the connections were permanent. However, this year, we used Wet Link penetrators with compression glands to allow for cables to be removed. We can screw in the penetrator to pressurize cable connection and unscrew to pressurize. Thus, we analyzed the failures of last year's design and adapted.

Our Ethernet connection will be crucial to our ROV, as it handles all control and sensor data. To test this, we hooked it up to our land ROV and were able to send signals for motor controls via ethernet. Through this, we realized that there are specific ethernet ip addresses that must be utilized in order to connect via ethernet; these addresses differ from the regular ip addresses.

Because we went through a series of refinements and iterations on the ROV design as well as our tools, it was essential that we develop a rigorous testing protocol to evaluate our progress. Testing allowed us to have immediate feedback on our design changes and highlighted areas that needed to be improved or validated that we were on the right path. Testing became critical when we transitioned from the bench to the pool. We did a dunk test in a water-filled 50 gallon trash bin to ensure we had watertight sealing. Once we knew it was watertight, the team performed numerous simulations of the RFP tasks in a swimming pool.

Lastly, in terms of props, we constructed many props in order to test the Aquatic ROV that we are constructing. These will be utilized in conjunction with the pool we have adjacent to the complex we are residing in while building the ROV.

FUTURE IMPROVEMENTS

We would like to include a more advanced suite of autopilot and autonomous control features such as depth hold to add greater ease of use for the pilot.

We would also like to build an arm with multiple angular degrees of freedom which would give the pilot more control over underwater manipulation.

ACCOUNTING

Because we are an independent and self funded team, we were extremely mindful of our budget and the costs associated with this year's competition. We began by looking at our limited budget and worked backwards to develop a basic breakdown of costs we felt we could incur with each component. Working within the constraints of a limited budget quickly taught us to be efficient and scrappy with our design and build. We harvested components such as thrusters and cameras from our prior MATE robots and became very adept at prototyping in cost effective ways to validate elements of the design prior to fabricating the final parts in more expensive materials. For instance, our tools were typically first prototyped in foam-board and PVC for testing and iteration before moving to laser cut acrylic or aluminum for the final iteration.

Having won a bid to the world championships, we quickly mobilized as a team to develop a fiscal strategy that would allow all of our members to attend. We created a GoFundMe campaign to appeal to our friends and family. We are also very fortunate to have a supportive community in our hometown of Santa Cruz that helped publicize our regional victory and our need for support.

ACCOUNTING SUMMARY

Expenses	
Purchased	-$12,555.00
Donated	-$2,702.00
Re-used	-$363.00
Total Expenses	**-$15,620.00**
Cash Flow	
Cash In	$15,000
Cash Outlay	-$12,555.00
Final Cash Balance	**$2,445.00**

Fig. 14. Accounting summary.

BUDGET

Income							
Source				Budgeted Amount	Actual	Cash In	
X Academy Funding				$5,000.00	$5,000.0	$5,000.00	
Expenses							
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Amount**	**Actual**	**Cash Outlay**	**ROV**
Mechanical	Purchased	Float Chamber, Pump	$1,000.00	$1,000.00	$589.00	$589.00	$589.00
Mechanical	Re-used	Thrusters and Motor Controllers	$2,000.00	$0.00	$1,733.00	$0.00	$1,733.00
Mechanical	Donated		$0.00	$0.00	$0.00	$0.00	$0.00
Electronics	Purchased	Lasers, PCB	$400.00	$400.00	$89.00	$89.00	$89.00
Electronics	Donated	Laptop, Monitor, and RC Controller	$2,600.00	$0.00	$2,599.00	$0.00	$2,599.00
Float	Purchased	PVC, Linear Acuator, Motor	$500.00	$500.00	$358.00	$358.00	$358.00
Float	Re-used	Motors, Raspberry Pi	$500.00	$500.00	$223.00	$0.00	223
Test	Purchased	Props and Pool Rental	$1,000.00	$1,000.00	$1,082.00	$1,082.00	
Regional	Purchased	Regional Cometition Registration Fee	$250.00	$250.00	$250.00	$250.00	
Regional	Donated	Travel to Regional Competition	$100.00	$100.00	$84.00	$0.00	
Totals			**$18,550.00**	**$13,950.00**	**$16,202.62**	**$11,563.62**	**$5,591.00**

Fig. 15. Budget.

COST ACCOUNTING

Date	Type	Category	Expense	Description	Amount	Source/ Notes	Amount	Running Balance	Purchased	Re-used	Donated
12/4/2022	Donated	Electronics	Top Side Electronics	RC Plane Controller	$299.00	SwitchBlox, MonoPrice	$299.00	$299.00	$ -	$299.00	$ -
12/4/2022	Donated	Electronics	Computer and Monitor	Computer Monitor	$800.00	Blue Robotics	$800.00	$1,099.00	$ -	$800.00	$ -
12/4/2022	Donated	Electronics	Laptop	MacBook	$1,500.00	Servo City, Arduino	$1,500.0	$2,599.00	$ -	$1,500.00	$ -
12/4/2022	Purchased	Mechanical	Manipulators	Gripper	$25.00		$25.00	$2,624.00	$ -	$ -	$25.00
12/4/2022	Re-used	Electronics	Servo Components	Water Proof Servo, Servo Boosters and Cables	$149.00	Donated by Team Member	$149.00	$2,773.00	$ -	$ -	$149.00
12/4/2022	Re-used	Electronics	On Board Network	Ethernet Switch, Ethernet Adapter for Pi Zero, Cables	$105.00	Donated by Team Member	$105.00	$2,878.00	$ -	$ -	$105.00
12/4/2022	Re-used	Electronics	Sensors	Depth Sensor	$103.00	Raspberry Pi and Arducam	$103.00	$2,981.00	$ -	$103.00	
12/4/2022	Re-used	Electronics	Top Side Electronics	Ardunio and Project Case	$204.00	Purchased from ServoCity, Amazon and Home Depot	$204.00	$3,185.00	$204.00	$ -	$ -
12/4/2022	Re-used	Electronics	On Board Electronics	Raspberry Pi 4, Raspeverry Pi Zero, Cameras and Cables	$189.00	Donated by X Academy	$189.00	$3,374.00	$189.00	$ -	$ -
12/4/2022	Re-used	Float	Motor	Actobotics Motors	$34.00	Purchased from Amazon	$34.00	$3,408.00	$34.00	$ -	$ -

12/4/2022	Re-used	Float	Raspberry Pi	Raspberry Pi 4	$189.00	Puchased from Home Depot	$189.00	$3,597.00	$189.00	$ -	$ -
12/4/2022	Re-used	Mechanical	Tether	Wire Rope, Cat 6 Cable, 12 AWG Zip Cord, Fuse Holder	$189.00	Servo City	$189.00	$3,786.00	$189.00	$ -	$ -
12/4/2022	Re-used	Mechanical	Frame	Actobotics Aluminum Channel and Parts	$283.00	Tap Plastic	$283.00	$4,069.00	$283.00	$ -	$ -
12/4/2022	Re-used	Mechanical	Propulsion	6 Thrusters and Electronics Speed Controllers from Blue Robotics	$1,236.00	Oak-D	$1,236.0(	$5,305.00	$1,236.00	$ -	$ -
12/4/2022	Re-used	Mechanical	Manipulators	Gripper	$25.00	Servo City	$25.00	$5,330.00	$25.00	$ -	$ -
2/1/2023	Purchased	Test	Props	PVC, Fish, Rebar, Spray Paint, String, Mesh	$362.00	PowerWerx, Amazon	$362.00	$5,692.00	$362.00	$ -	$ -
2/3/2023	Purchased	Electronics	Lasers, PCB	Lasers, PCB	$24.00	MATE	$24.00	$5,716.00	$24.00	$ -	$ -
3/1/2023	Purchased	Competition	Registration Fee	Registration Fee for Monterey Regional Competition	$250.00		$250.00	$5,966.00	$250.00	$ -	$ -
3/5/2023	Purchased	Mechanical	Float Chamber	Blue Robotics Tube and Components	$564.00		$564.00	$6,530.00	$564.00	$ -	$ -
4/22/2023	Donated	Regional	Mileage	Santa Cruz to Watsonville - 15 miles x 2 ways x 5 cars x $0.56 IRS milage rate	$84.00		$84.00	$6,614.00	$ -	$ -	$84.00
5/10/2023	Purchased	World	Fuel and Lodging	Vans from Santa Cruz, CA to Longmont, CO	$1,823.00		$1,823.0(	$8,437.00	$1,823.00	$ -	$ -
5/10/2023	Purchased	World	Lodging	Hotels in Longmont, CO	$7,183.00		$7,183.0(	$15,620.0(	$7,183.00	$ -	$ -
12/4/2022	Donated	Electronics	Top Side Electronics	RC Plane Controller	$299.00		$15,620.(		$12,555.00	$2,702.00	$363.00
Totals					**$15,620.0(**						

Fig. 16. Cost accounting.

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Underwater cover image: Photo by Ali Abdul Rahman on Unsplash